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AN UNMANNED PROBE TO PLUTO N91-18196

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Now that Voyager II has completed its grand tour of the solar system, all the planets in the solar system, with the exception of Pluto, have been studied. Even now, missions to return to Mercury, Venus, Mars, Jupiter, and Saturn are currently flying or are planned. However, a mission to explore Pluto is not, at the present time, being considered seriously. The design problem presented to the students was very general, i.e., design an unmanned mission to Pluto with a launch window constraint of the years 2000-2010. All other characteristics of the mission, such as mission type (flyby, orbiter, lander, penetrator), scientific objectives and payload, and the propulsion system were to be determined by the design teams. The design studies exposed several general problems to be solved. Due to the extreme distance to Pluto (and a corresponding travel time in the range of 10 to 25 years), the spacecraft had to be lighter and more robust than current spacecraft designs. In addition, advanced propulsion concepts had to be considered. These included the new generation of launch vehicles and upper stages and nuclear electric propulsion. The probe design offered an abundance of synthesis and analysis problems. These included sizing trade studies, selection of subsystem components, analysis of spacecraft dynamics, stability and control, structural design and material selection, trajectory design, and selection of scientific equipment. Since the characteristics of the mission, excluding the launch window, were to be determined by the design teams, the solutions varied widely.

INTRODUCTION

Although missions to return to Mercury, Venus, Mars, Jupiter, Saturn, and comets are planned or currently flying, a mission to Pluto is not planned until after 2010. The first step in the exploration of Pluto will occur when Hubble Space Telescope becomes active. This instrument should provide clearer pictures of Pluto and Charon than currently exist. However, even this clarity will not be sufficient to perform the analyses necessary to answer the current questions about Pluto and Charon.

To provide scientists with the data required to perform those analyses, a mission to Pluto and Charon is necessary. There are three classes of missions that can be flown: (1) flyby, (2) orbiter, and (3) lander. Flyby missions have an inherent limitation in the amount of time spent in the vicinity of the area of interest. However, they are the easiest to design and the least expensive to build and fly.

Orbiter missions are inherently more costly than flyby missions because of the requirement to enter orbit about the body of interest. However, this type of mission provides more time to study the body of interest, allowing additional and more exact experiments to be performed. Because of the distance from Earth to Pluto, this type of mission must be able to adapt to the environment the spacecraft encounters.

The most costly mission class is the lander. There exist two subclasses of landers: a lander, which lands softly on the surface of the body in question, and a penetrator, which explores the area under the surface of the body. A lander mission provides the most accurate and largest quantity of data about another body. For this type of mission, an important question is which body to land on, Pluto or Charon?

PROJECT BACKGROUND

Forty-two undergraduate students, divided into seven groups, were enrolled in the spacecraft section of Aeronautical and Astronautical Engineering (AAE) 241, Flight Vehicle Design, in the spring 1990 semester. This paper summarizes the work of those student groups as submitted in their final design reports.

Today, little is known about plutonian space and current discoveries raise more questions than they answer. The Hubble Space Telescope should be able to answer some of the questions, but the only way to answer most of the questions is to send a spacecraft to Pluto to take data first hand.

Pluto, the ninth planet in our solar system, was discovered in March 1930, using photographic plates taken in January of that year. Charon, Pluto's only known satellite, was discovered in July 1978, but not recognized until 1985. With an eccentricity of 0.25 and a perihelion of 29.6 A.U., Pluto has an orbital period of 248 years.

Pluto itself is estimated to weigh about 1/400 of the mass of the Earth, with a diameter of approximately 2300 km. The composition of the planet is estimated to be about 70% rock and 30% water ice and methane ice. The atmosphere is believed to be composed mostly of methane, which is sublimating from the surface, with traces of heavier gases such as argon, neon, and nitrogen. Due to the large eccentricity of the orbit and the distance from the sun, the atmosphere of Pluto is thought to form and collapse cyclically as a function of the orbital period. The next collapse is expected to occur around 2025.

PROJECT OBJECTIVE

The project objective was to develop a conceptual design for a spacecraft to perform an unmanned scientific study of plutonian space to be launched sometime in the first decade of the 21st century. Performance, weight, and cost are very important to the acceptance of this type of mission, so approaches were taken that optimize these parameters in design tradeoffs. The spacecraft had to be reliable and use off-the-shelf hardware whenever available. The use of materials or techniques expected to be available after 1999 was prohibited.

SYSTEM REQUIREMENTS

A thorough preliminary design study was conducted by the students to determine major design issues, establish the size of, define subsystems for, and describe the operation of the spacecraft that satisfies the following requirements:

1. The amount of on-orbit assembly should be identified and minimized.
2. The following subsystems are identified for the purposes of system integration: (a) science instrumentation; (b) mission management, planning, and costing; (c) attitude and articulation control; (d) command, control, and communication; (e) power and propulsion; and (f) structure (including materials and thermal control).
3. The usage of the space shuttle should be identified. If the space shuttle is used for launch, the payload/shuttle interfaces must conform to NASA standards.
4. Nothing in the spacecraft's design should preclude it from performing several possible missions.
5. The spacecraft should have a design lifetime sufficient to carry out its mission plus a reasonable safety margin, but nothing in its design should preclude it from exceeding this lifetime.
6. The vehicle should use the latest advances in artificial intelligence where applicable to enhance mission reliability and reduce mission costs.
7. Mission science objectives must be described and justified.
8. The design should stress reliability, simplicity, and low cost.
9. For cost estimating and overall planning, it should be assumed that four spacecraft will be built. Three will be flight ready, while the fourth will be retained for use in an integrated ground-test system.

SCIENCE INSTRUMENTATION

The students working in this area were to determine the science objectives for the mission. In addition, they were to select the instruments necessary to fulfill these objectives. Some of the selected objectives were (1) determine the composition and structure of Pluto's atmosphere; (2) study the dynamics of the Pluto/Charon system; (3) determine the mass, composition, and structure of Pluto; (4) determine the mass, composition, and structure of Charon; (5) determine the surface characteristics of Pluto; (6) determine the existence and structure of the magnetic field of Pluto; (7) study Jupiter (during a gravity assist maneuver); and (8) search for other satellites in the Pluto/Charon system.

The instruments chosen to meet these objectives can be divided into two major groups, remote sensing and fields and particles. The remote-sensing instruments were determined to be the most important, with all seven groups selecting both narrow- and wide-angle cameras and ultraviolet spectrometers. These instruments provide information to help determine the composition and structure of the bodies and the atmosphere, and provide for the search for additional satellites in the Pluto/Charon system. Pictures of the system taken by the cameras will help determine its dynamics.

The fields and particles instruments will be used for interplanetary science experiments during the voyage to Pluto and will be used to study the magnetic field of Pluto, if one exists. The instruments selected include magnetometers, selected by six groups, and plasma particle detectors, selected by six groups. Figure 1 shows the layout of a representative science platform.

Example Science Scan Platform

- **Mounted on a Two Degree-of-freedom Actuator**
- **Aimed with the Narrow Field-of-view Camera**
- **Deployed on an Extendable Boom**

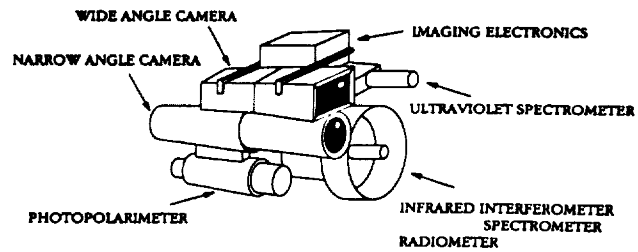

Fig. 1. Example Science Scan Platform

MISSION MANAGEMENT, PLANNING, AND COSTING

Mission management was responsible for the selection of a trajectory to Pluto and a launch vehicle for the spacecraft. Table 1 shows the types of missions chosen and the duration of the missions. Five of the seven groups selected a flyby mission, like Voyager, whereas the other two felt the additional data-gathering capabilities provided by the orbiter were important. The duration for the flyby missions ranged from 13 to 19 years, while the orbiter missions were 22 and 15 years respectively. Note that Group 7 utilized a nuclear-electric propulsion system. Note also that all seven spacecraft are expected to arrive in plutonian space prior to the predicted collapse of the atmosphere of Pluto.

Table 1. Mission Type and Duration Summary

Group	Mission Type	Launch Date	Arrival Date	Mission Time (yrs)
1	Flby	09/2000	05/2018	18
2	Flyby	02/2002	02/2017	15
3	Flyby	01/2002	09/2020	19
4	Orbiter	12/2004	01/2025	22
5	Flyby	01/2003	02/2019	16
6	Flyby	05/2009	12/2021	13
7	Orbiter	04/2004	04/2019	15

For the six groups using the classical chemical propulsion systems, a tool call MULIMP was used to help determine a trajectory for the spacecraft. As shown in Table 2, a variety of trajectories were selected. These include a Jupiter Gravity Assist (JGA), where the spacecraft leaves the Earth and performs a gravity assist maneuver at Jupiter in order to increase the speed of the spacecraft and shorten the trip time.

Another trajectory was the Earth-Jupiter Gravity Assist (EJGA) where the spacecraft leaves Earth's sphere of influence, performs a gravity assist maneuver at Earth, and then performs another gravity assist maneuver at Jupiter before proceeding on to Pluto. One group chose to fly directly to Pluto without any interplanetary flybys or gravity assists in order to get to Pluto before the atmosphere collapsed. The final chemical trajectory performed gravity assist maneuvers at both Jupiter and Saturn on the way to Pluto (JSGA).

Table 2. Trajectory and Launch Vehicle Summary

Group	Launch Vehicle	Trajectory	Delta V (km/sec)	Propulsion Type
1	Titan IV/Centaur	JGA	11.2	Chemical
2	Titan IIID/Centaur	EJGA	7.5	Chemical
3	Titan Commercial/ TOS	EJGA	5.9	Chemical
4	Shuttle C/STV	JGA	12.1	Chemical
5	Ariane IV	DIRECT	8.6	Chemical
6	Titan T-34D/ Centaur	JSGA	12.4	Chemical
7	Shuttle C	JGA	N/A	Nuclear Electric

N/A - Not Available; E - Earth; J - Jupiter; S - Saturn; GA - Gravity Assist

Group 7 uses a nuclear-electric propulsion system. The analysis of this trajectory was performed using a tool called CHEBY2. However, this program does not provide for gravity assist maneuvers. This spacecraft spirals out of Earth's sphere of influence beginning in nuclear-safe orbit. The spacecraft performs a gravity assist maneuver at Jupiter and finally spirals into an orbit about Pluto.

The total costs of the missions were determined using the Science Applications International Corp. Planetary Cost Model. This model includes design, development, testing and evaluation, the four flight vehicles required by the RFP, and the ground support personnel required during the entire mission. For the chemical systems, the estimated costs range from $1.03 billion to $2.11 billion in 1990 dollars while the nuclear-electric orbiter's estimated cost is $4.21 billion.

ATTITUDE AND ARTICULATION CONTROL

For attitude determination, all seven groups chose to use a sun sensor and the ASTROS star sensor for determining attitude. Also, all the groups used the Fiber Optic Rotational Sensor (FORS) as the gyroscope to be used most of the time.

For control, all groups selected a three-axis active control system over spin-stabilized or dual-spin configurations. All seven groups chose to use thrusters as the method of attitude correction, with the electric propulsion group using reaction wheels, as well, for stability. For the attitude control thrusters, the six chemical groups used monopropellant hydrazine as the propellant, while the electric propulsion group used ionic mercury as the propellant.

In order to isolate the motion of the science instruments from the rest of the spacecraft, all seven groups chose to put the instruments requiring pointing on a scan platform. This scan platform was gimballed in two axes in order to provide the equipment with the widest field of view. The most common scan platform selected was the High-Performance Scan Platform (HPSP).

COMMAND, CONTROL, AND COMMUNICATION

This subsystem is responsible for selecting the communications equipment as well as the "brains" of the spacecraft.

For the communications portion, a large antenna is required in order to communicate over such a large distance. In addition, the distance necessitates a large power supply. Also, adequate storage for the scientific data obtained is required when the spacecraft is unable to communicate with Earth or when the data input is greater than the communications rate.

As shown in Table 3, the antenna sizes ranged from 1.5 m to 4.8 m with 4.8 m used most frequently. Also, most groups used the proposed upgrades in the deep space network (DSN) in order to improve communications capability. These upgrades included increasing the size of the primary receiver to 70 m and making the antennas Ka-band capable. For communications, the data rates ranged from 300 bps to 388,000 bps. Powers ranged from 6.3 W to 25 W, except for the nuclear-electric orbiter, which used a power of 1000 W.

Table 3. Antenna Sizing Summary

Group	Size (m)	Band	Transmitted Power (W)	DSN Receiver Size (m)	Data Rates (bps)
1	4.8	Ka	20	70	316,891
2	1.5	X	13	64	300
3	4.8	Ka	10	70	145,500
4	4.8	Ka	6.3	70	388,000
5	2.5	X	20	70	N/A
6	3.7	X	25	64	N/A
7	4.8	Ka	1000	70	N/A

POWER AND PROPULSION

The selection of the method for supplying electric power to the spacecraft was based on a combination of the mission length, the distance from the sun, and the peak power loads. For the power supply, Pluto is too far from the sun for practical use of solar radiation. The mission times are too long for batteries to be able to store energy for the entire voyage. This leaves a nuclear power supply as the only viable option. Of the different types of nuclear power sources, five groups chose the modular isotopic thermoelectric generator (MITG), one group chose a type of radioisotope thermoelectric generator (RTG), and one group chose a nuclear reactor.

Once the power supply has been selected, the size of the power supply must be determined. This is a function of the peak power required, and the duration of the mission. The power selections are summarized in Table 4. Again, the group using the electric propulsion has a vastly different power supply. They plan to carry two SP-100 nuclear reactors to supply all the power needs of the spacecraft.

Table 4. Power Supply Summary

Group	Mission	Mission Duration (yrs)	Peak Power (W)	Power Supply	Number of Slices	Mass (kg)
1	Flyby	18	297	MITG	13	29.1
2	Flyby	15	256	MITG	15	34.0
3	Flyby	19	165	MITG	2 × 11	49.9
4	Orbiter	22	237	RTG	1*	26.0
5	Flyby	16	373	MITG	23	44.4
6	Flyby	13	290	MITG	13	60.0
7	Orbiter	15	80,500	Reactor	2*	4600.0

MITG = Modular Isotopic Thermoelectric Generator.
RTG = Radioisotope Thermoelectric Generator.
* Indicates the number of power units where slices are not applicable.

The responsibilities in the propulsion area were propellant selection, propellant tank sizing, and orbit insertion propulsion for the two orbiters. For this mission, four chemical propulsion options were considered: cold gas, solids, monopropellants, and bipropellants. Cold gas and solids are not applicable to the mission. Three groups selected the monopropellant hydrazine because it is simple, reliable, storable, and has relatively low cost. The other three chemical groups chose the more complex, but higher I_{sp} bipropellant, hydrazine and nitrogen tetroxide.

The nuclear-electric propulsion system is different. The propellant options investigated for this system include cesium, xenon, argon, and mercury. Of the four options, mercury was selected because it provides the best tradeoff between cost, storability, and I_{sp}.

For the chemical systems, the propellant mass ranged from 473 kg to 2000 kg for the flyby missions and 3120 kg for the orbiter. The nuclear-electric mission had a propellant mass of 12,000 kg.

STRUCTURES

This subsystem was responsible for locating the components, determining the mass properties, and thermal control. Figures 2 through 4 show the layout of three representative spacecraft: Fig. 2 is a flyby, Fig. 3 is an orbiter, and Fig. 4 is the nuclear-electric propulsion orbiter.

Locating the components and determining the mass properties must be performed together. The components should be arranged on the spacecraft to minimize the cross product of inertia about the axes of the thrusters. This is the principle reason for the arrangements shown in Figs. 2 through 4.

Thermal control is required in order to maintain the temperature within acceptable limits for all components within the spacecraft. Various methods were employed by the groups. The most widely selected method was the placement of thermal heaters throughout the interior of the spacecraft. Radioisotope heating units, where the energy from nuclear decay is used to heat nearby components, were also common. The nuclear-electric orbiter used high-temperature radiators to remove the waste heat from the nuclear reactor.

For the chemical flyby missions the structure (dry) masses range from 445 kg to 756 kg with the total masses ranging from 1093 kg to 2500 kg. The chemical orbiter has a dry mass of 3243 kg and a total mass of 6363 kg. The nuclear-electric orbiter has a dry mass of 8914 kg and a total mass of 20,914 kg.

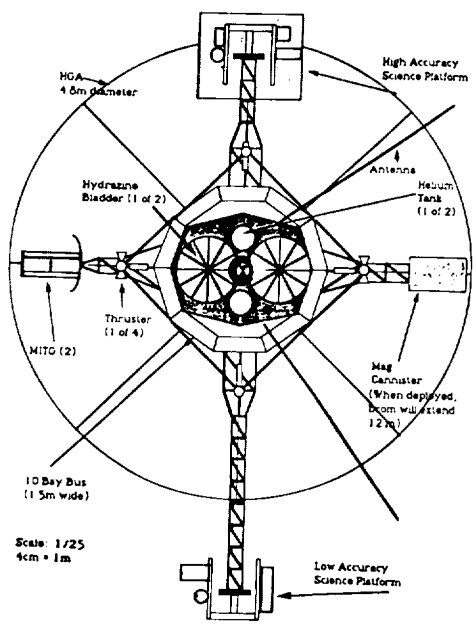

Fig. 2. Bottom View of an Example Flyby Spacecraft

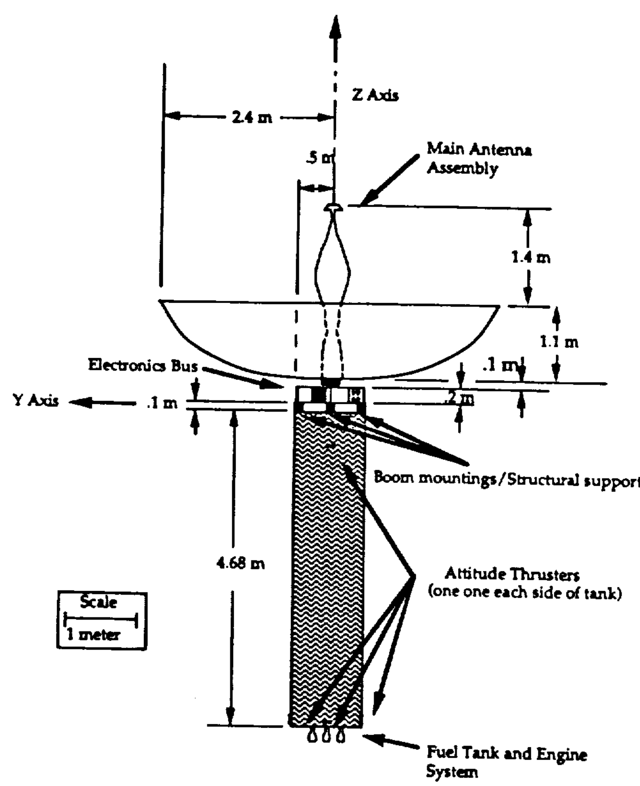

Fig. 3. Side View of an Example Orbiter Spacecraft

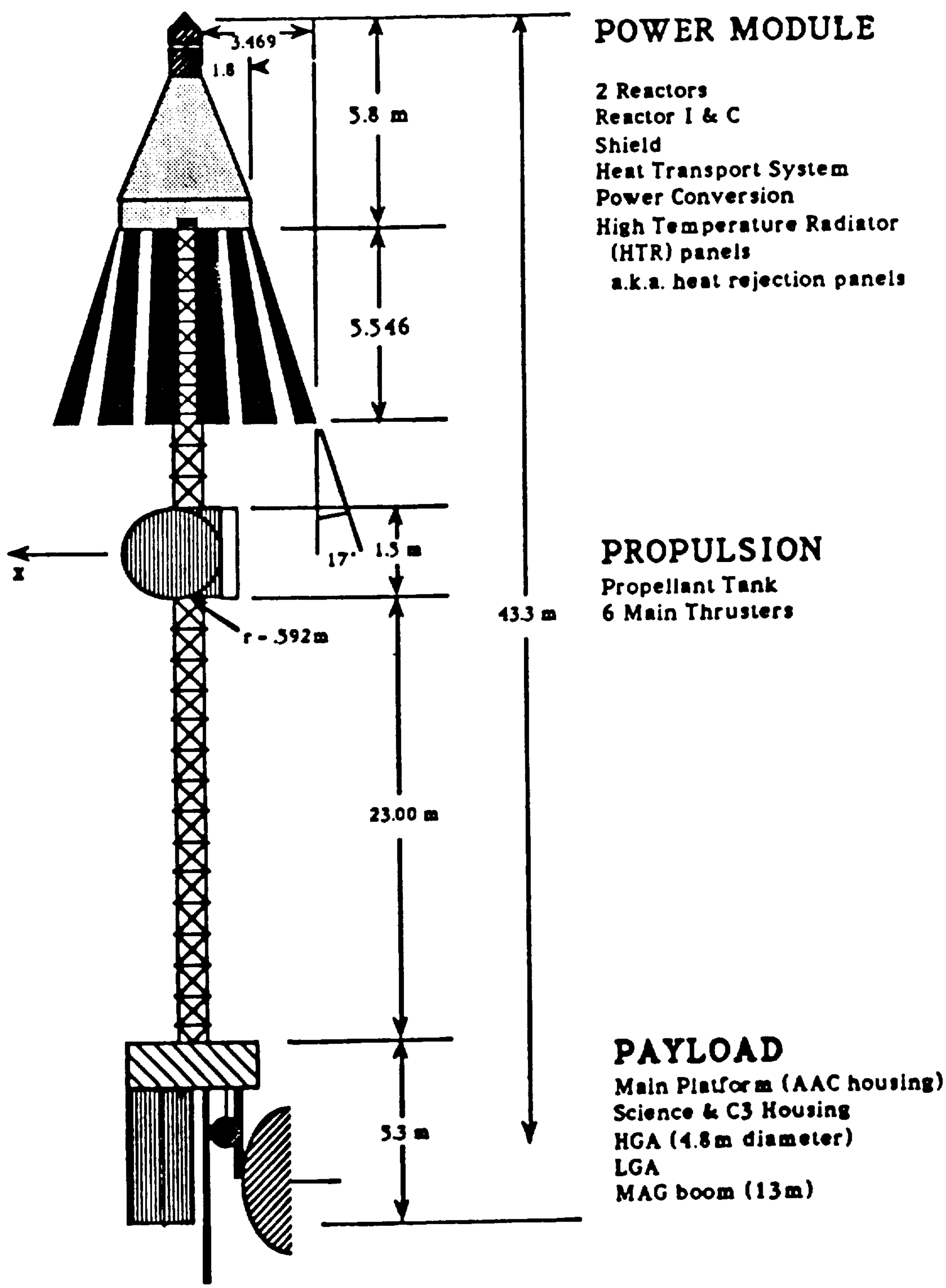

Fig. 4. Side View of the Nuclear-Electric Orbiter Spacecraft